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ABSTRACT

Robots are finally receiving wide-spread attention as a means to realize the goal of automating factories. In the 1960's robot use was limited by unfavorable acquisition and operating costs and the affordable control technology limiting applications to relatively simple jobs. During the 1970's productivity of manufacturing organizations declined while labor rates increased. The control, flexibility, reliability, and manipulative capabilities of robots improved. Robots are currently used where they offer advantages in processes characterized by a high degree of order, repetition, and moderate production volumes. They, of course, produce better than humans when they have capabilities humans do not have. While robots have limited decision making capabilities, more elaborate and useful sensing systems are readily available and the affordable cost of more complex controls is enhancing robots' capability to deal with more and difficult tasks. To raise the level of understanding of the application of robot capabilities, more robotics programs are being developed in secondary and postsecondary institutions, information on productivity advances is being disseminated, and curricula in robot application and maintenance are being developed. (A bibliography and 18 pages of charts, tables, and photographs are provided.) (YLB)

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ROBOTICS: PAST, PRESENT AND FUTURE

A PAPER PREPARED FOR

THE 1982 CONVENTION OF

THE AMERICAN VOCATIONAL ASSOCIATION

St. Louis, Missouri
December, 5, 1982

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DANBURY, CONNECTICUT

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TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Introduction:

Twenty years after their introduction to the industrial scene, robots are receiving wide-spread enthusiasm as the miracle devices which will precipitate the realization of the manufacturing executives dream ---- the automated factory.

Is this really true? If it is, why has it taken so long for robots to achieve recognition? Perhaps an analysis of the history of robotics; where they are being used today, and a look at their realizable potential in the near future, will help to answer the question.

Even more important: Are we ready to provide training to meet the demand for professionally oriented people who know how to apply them, install them, program them, and maintain them?

A Brief History:

First of all, what is a robot anyway? For many years it was vaguely spoken of as a form of flexible automation which could be moved from one job to another without extensive rework. It wasn't until the formation of the Robot Institute of America (RIA) that a workable definition (generally accepted in the U.S. and Europe) was formulated:

"A reprogrammable, multi-functional manipulator designed to move material parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks".

The Japanese Industrial Robot Association (JIRA) has a more flexible definition which ranges from manual manipulators which perform a totally fixed sequence to "intelligent robots" that can perform difficult tasks because they are able to use sensors such as vision and touch.

The Industrial Robot is a product of U.S. technology and the first one was installed in a General Motors plant in 1961 by Unimation, Inc., the first company whose sole business and only product is robots. The earliest applications were simple ones, such as unloading die cast machines, where the work was hard and the environment uncomfortable. Another early application was the use of robots in the resistance spot welding of automobile bodies.

Robots were introduced to Europe in 1965 and to Japan in 1968. It was not until the mid 1970's, however, that their usage in manufacturing began to increase significantly despite the fact that earlier predictions envisioned a growth similar to those predictions made for the computer industry. There were several reasons why the forecasts were premature. In the economic climate of the 1960's the acquisition and operating cost of a robot compared unfavorably with human labor, particularly since unfamiliarity with the technology made people apprehensive enough to demand one to one and a half year payback. In addition, the affordable control technology limited the applications to relatively simple jobs.

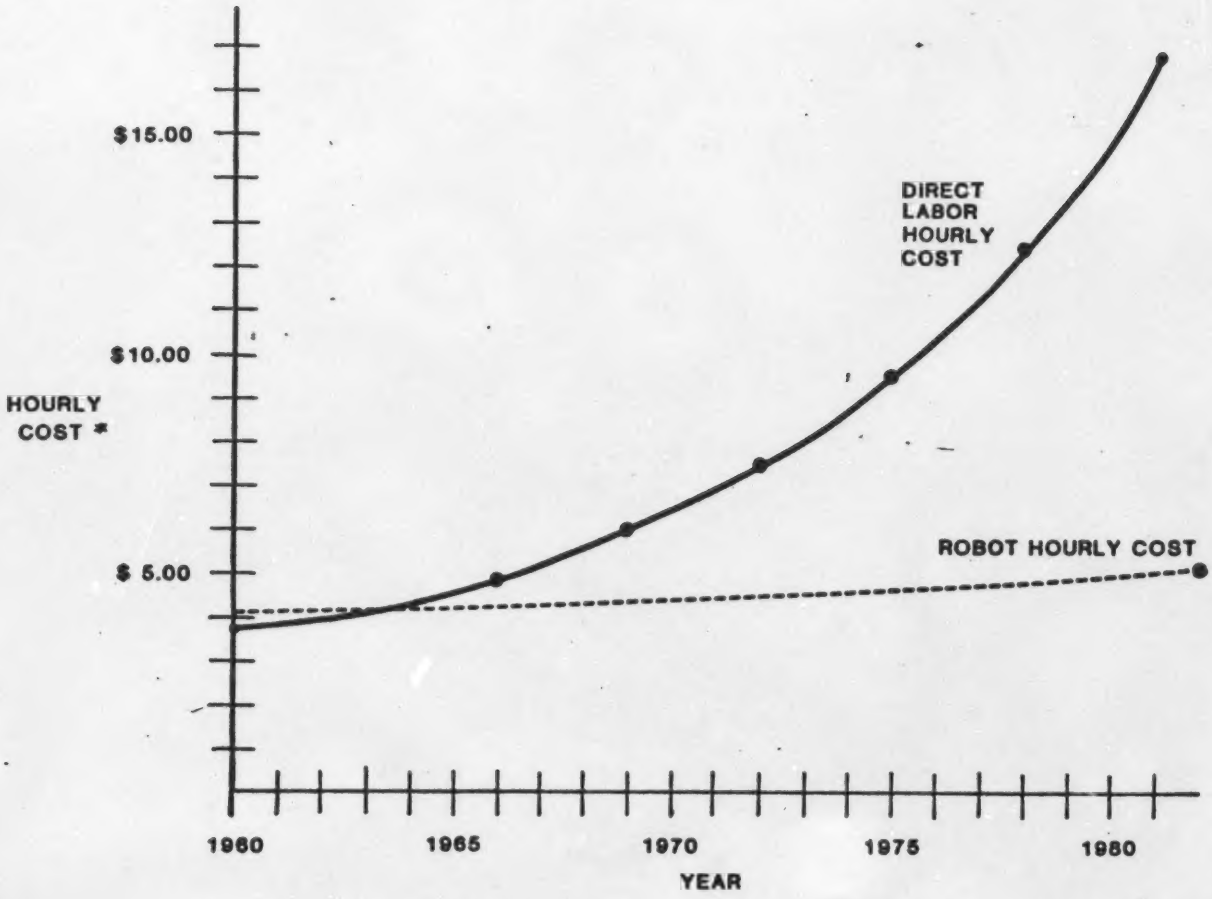
As a result, by 1970, only about 200 robots were in use throughout the U.S. At about this time, however, the economic environment changed considerably. The productivity growth of manufacturing organizations declined while labor rates increased. These trends occurred at the same time as the gradual acceptance of the robots flexibility and reliability emerged. In addition, the control, flexibility and manipulative capabilities of robots were being improved.

Similar trends appeared overseas, quite remarkably so in Japan. If we debate the Japanese capability for originating technology we cannot deny their capability for adopting and using it. Japan has more robots in use, more research and investigative organizations, and more funded and committed programs for extending the use of robots, than the whole rest of the world.

This remarkable onset of interest in robots has led, inevitably, to competition. In 1977 there were only three U.S. companies, about half a dozen European and about fifty Japanese; there are now more than two dozen in the U.S. alone and one or more robot manufacturers can be found in even the smallest industrialized country.

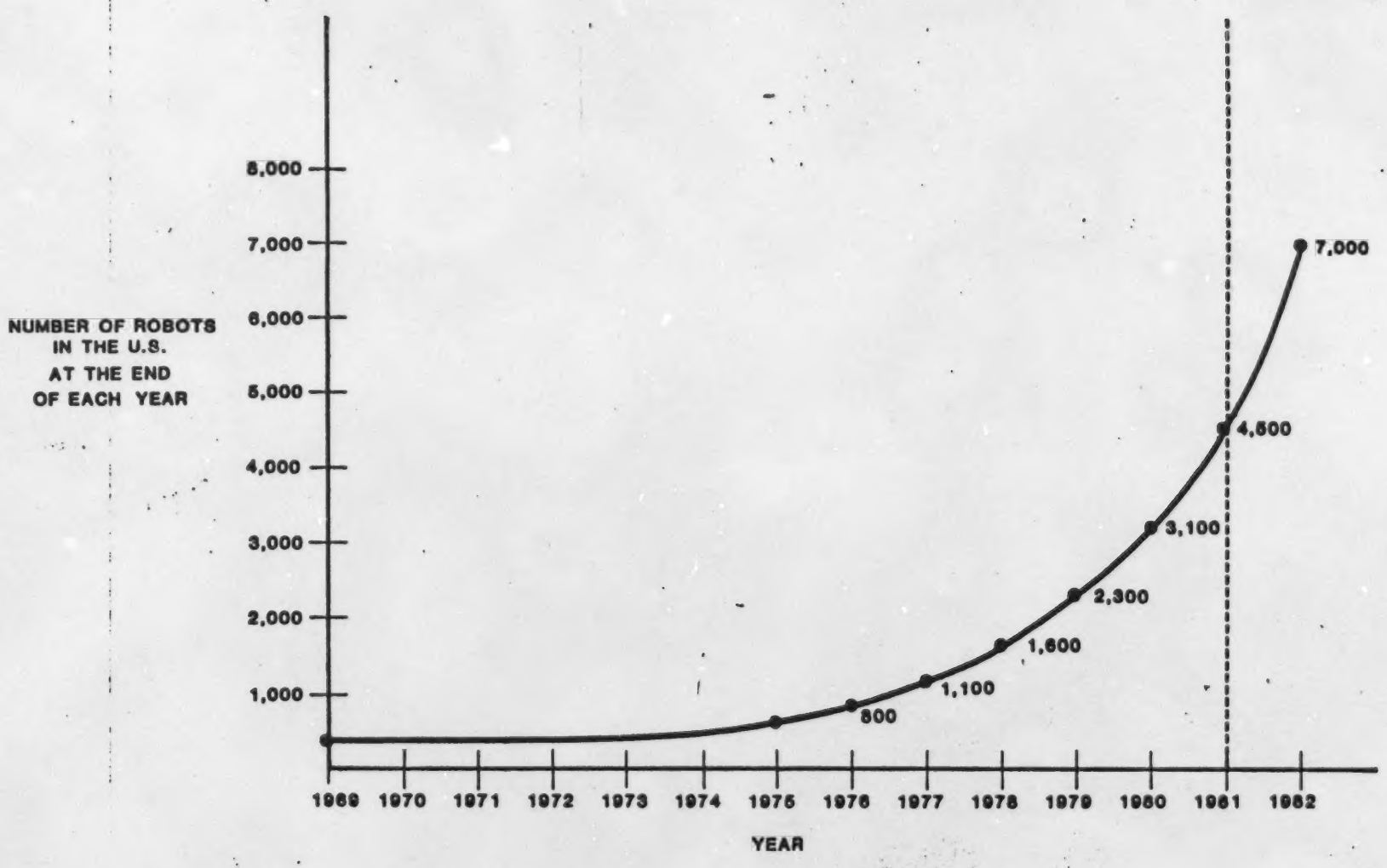
The same sort of surge has occurred among robot users. Industrial Robot Associations have sprung up all over the world. We are even beginning to see competition among users of the "my company uses more robots than your company" nature.

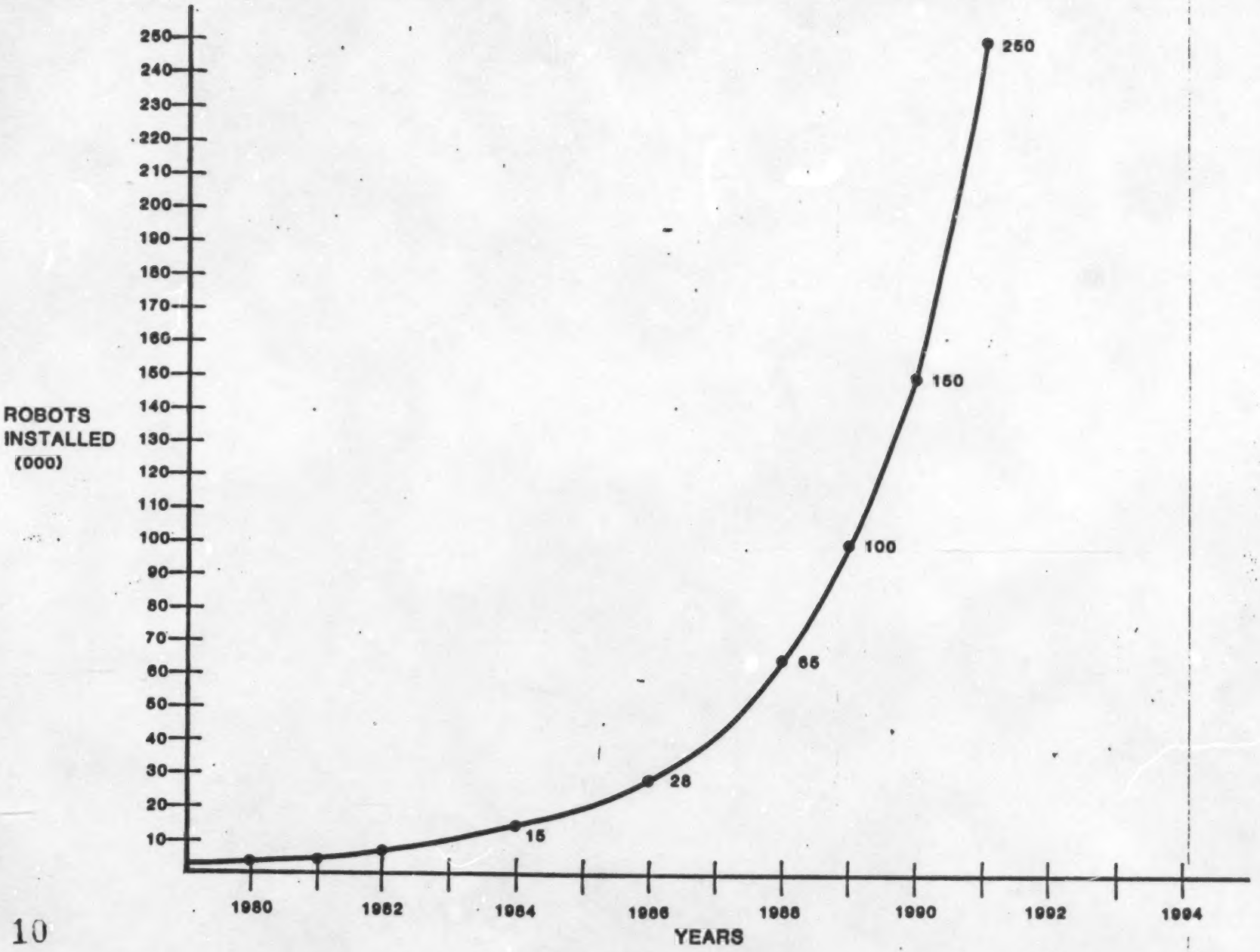
HOURLY LABOR COST OF AUTOMOTIVE WORKER VS. INDUSTRIAL ROBOT IN THE U.S., 1960-1981



* DIRECT LABOR COST INCLUDES FRINGE BENEFITS: ROBOT COST INCLUDES SUPPORT

NUMBER OF ROBOTS IN USE IN U.S. MANUFACTURING PLANTS





CUMULATIVE TOTAL OF U.S. ROBOTS

Where Are Robots Used:

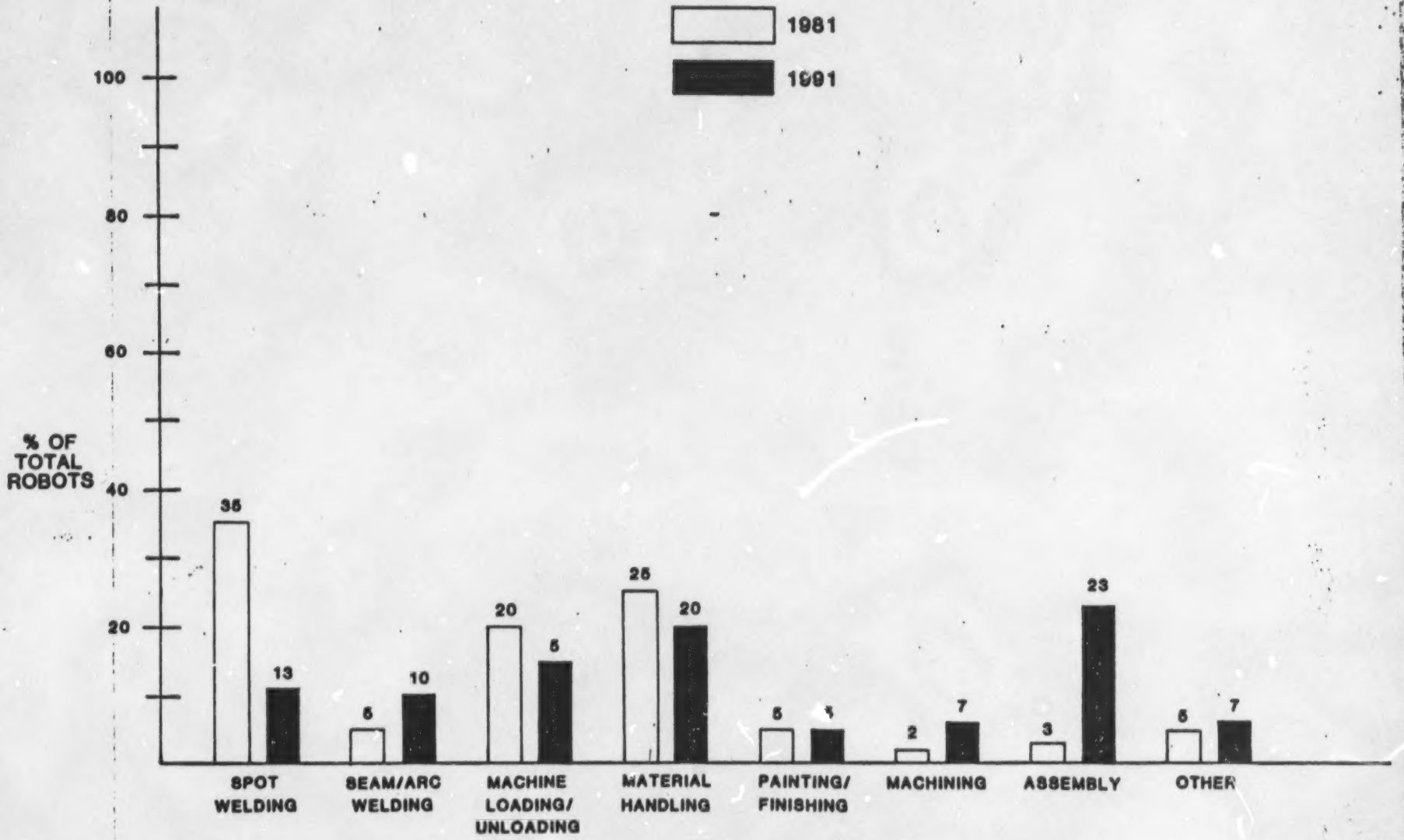
The number of different applications for which industrial robots can be used is far greater than the number of different robot models available. Their usage is more a function of the characteristics of the manufacturing process than it is the nature of the product. Generally, robots offer advantages in processes characterized by a high degree of order, repetition and moderate production volumes. We find them, then, in machine loading and unloading, welding, spray painting, palletizing, foundry work, and general material handling.

In general, robots compare favorably with humans in the following cases:

* When robots have capabilities that humans do not have (e.g. greater strength, greater environmental tolerance).
* When robots can perform a task better than humans (e.g. better accuracy, lower cost, higher reliability).
* When the job should not be done by humans (e.g. physical danger, drudgery).

Also, in general, robots fit well into the manufacturing process where:

* Batch production, rather than mass production, obtains.
* More than one shift occurs regularly.
* Median complexity is the rule.
* An orderly environment with a high degree of structure is present.



U.S. ROBOT APPLICATIONS

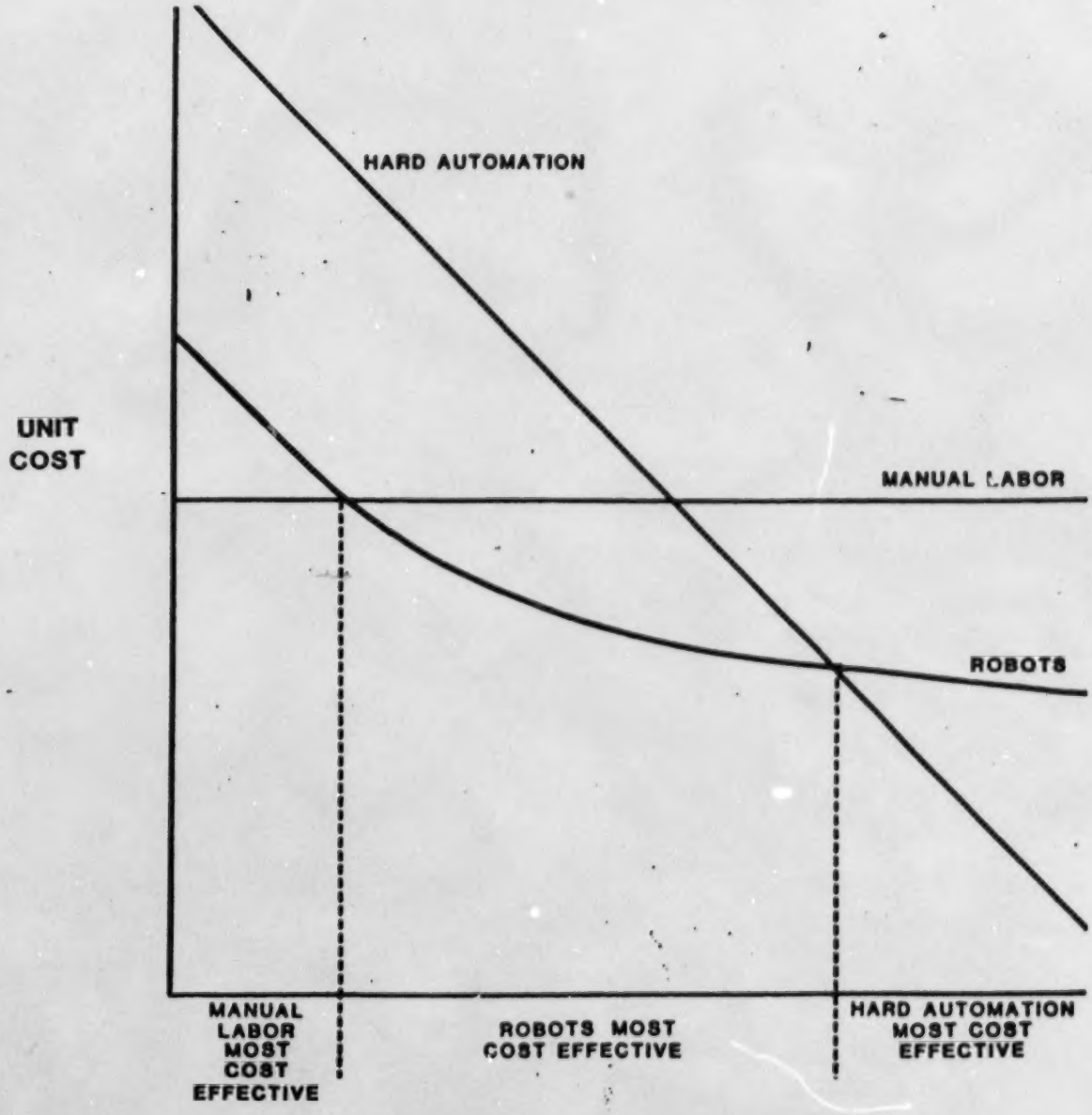
COMPARISON OF MANUFACTURING ALTERNATIVES: CAPABILITIES, MANUFACTURING CHARACTERISTICS, AND PERFORMANCE

		HARD AUTOMATION	ROBOTS	MANUAL
CAPABILITIES	TRANSPORT	EXCELLENT	GOOD	LIMITED
	MANIPULATION	NEGLIGIBLE	SIMPLE MANIPULATION	COMPLEX MANIPULATION
	SENSING	NONE	LIMITED SENSING	COMPLEX SENSING
	FLEXIBILITY	NONE	MODERATE	HIGH

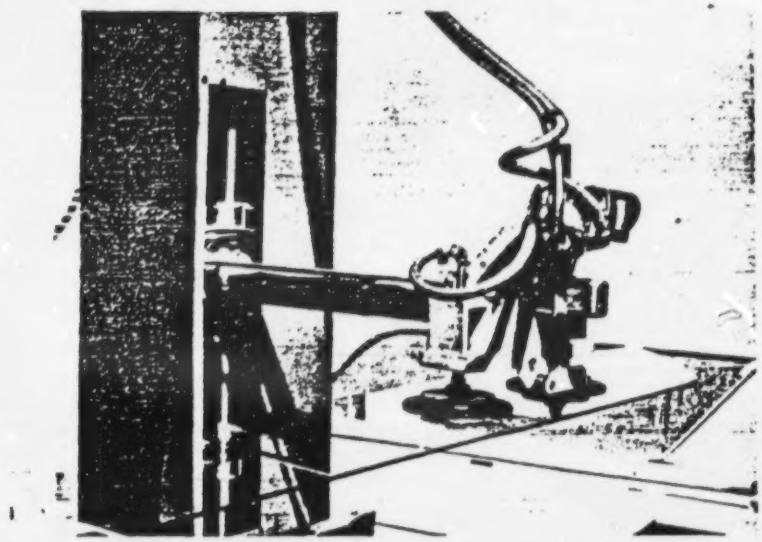
MANUFACTURING CHARACTERISTICS WHERE SUITABLE	TYPE OF OPERATION	MASS PRODUCTION	MASS/BATCH	BATCH/JOB SHOP
	NUMBER OF SHIFTS	2-3	2-3	1
	COMPLEXITY OF TASK	LOW	MEDIUM	HIGH
	DEGREE OF STRUCTURE	HIGH	HIGH	LOW
	PRODUCTION VOLUME	LONG RUN	MEDIUM RUN	SHORT RUN
	PRODUCTION RATE	HIGH SPEED	SLOW SPEED	SLOW SPEED
	DEGREE OF HAZARD	NO LIMIT	NO LIMIT	NON-HAZARDOUS ONLY

PERFORMANCE	QUALITY	HIGH	HIGH	MEDIUM
	PRODUCTIVITY	HIGH	MEDIUM	LOW
	OPERATING COSTS	LOWEST FOR LONG RUN, HIGH SPEED PRODUCTION	LOWEST FOR MEDIUM RUN, SLOW SPEED PRODUCTION	LOWEST FOR SHORT RUN, SLOW SPEED PRODUCTION

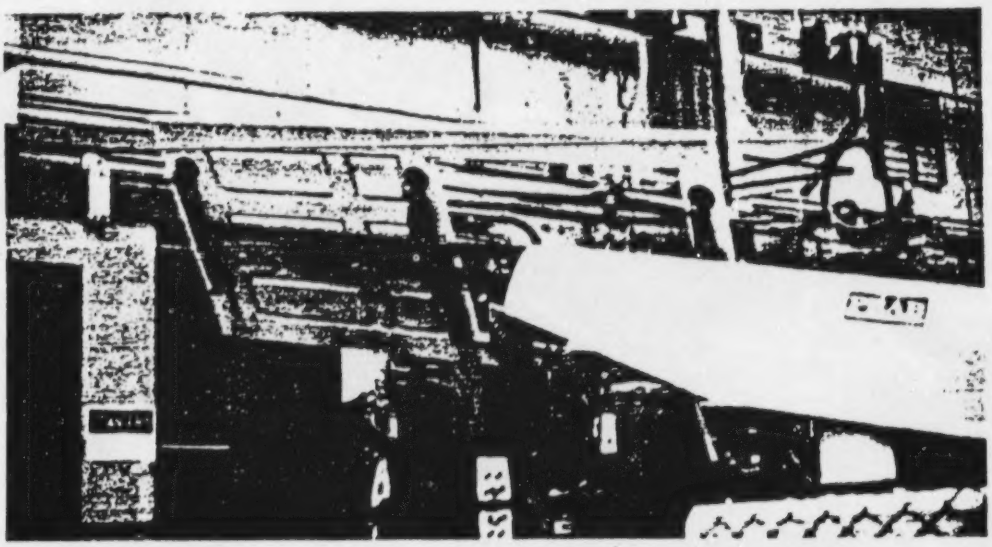
COMPARISON OF MANUFACTURING METHOD UNIT COSTS, BY LEVEL OF PRODUCTION



EXAMPLES OF MATERIAL HANDLING AND MACHINE LOADING APPLICATIONS OF ROBOTS

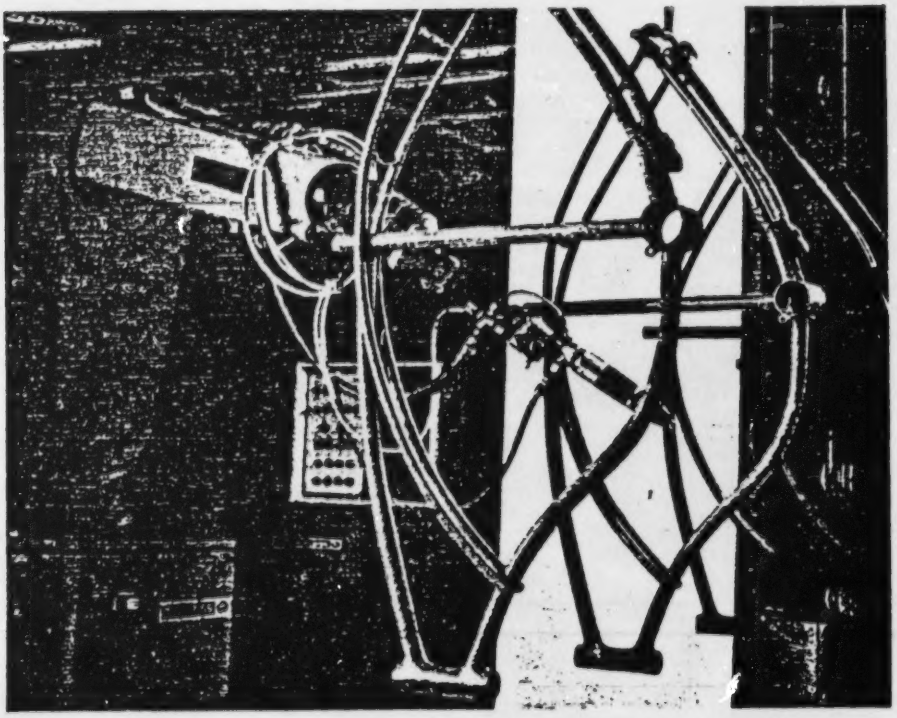


A PRAB MODEL E ROBOT STACKS AUTOMOBILE WINDSHIELDS (PHOTOGRAPH COURTESY OF PRAB ROBOTS, INC.)



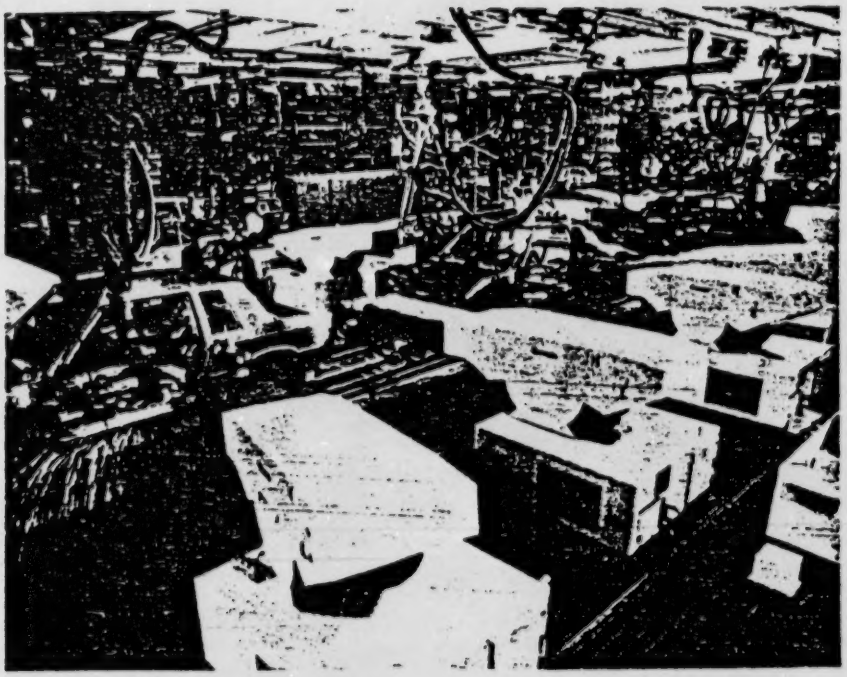
A PRAB MODEL 4200 ROBOT UNLOADS A PLASTIC DOOR FROM A FOAM MOLDING MACHINE (PHOTOGRAPH COURTESY OF PRAB ROBOTS, INC.)

EXAMPLE OF ROBOT SPRAY PAINTING APPLICATION



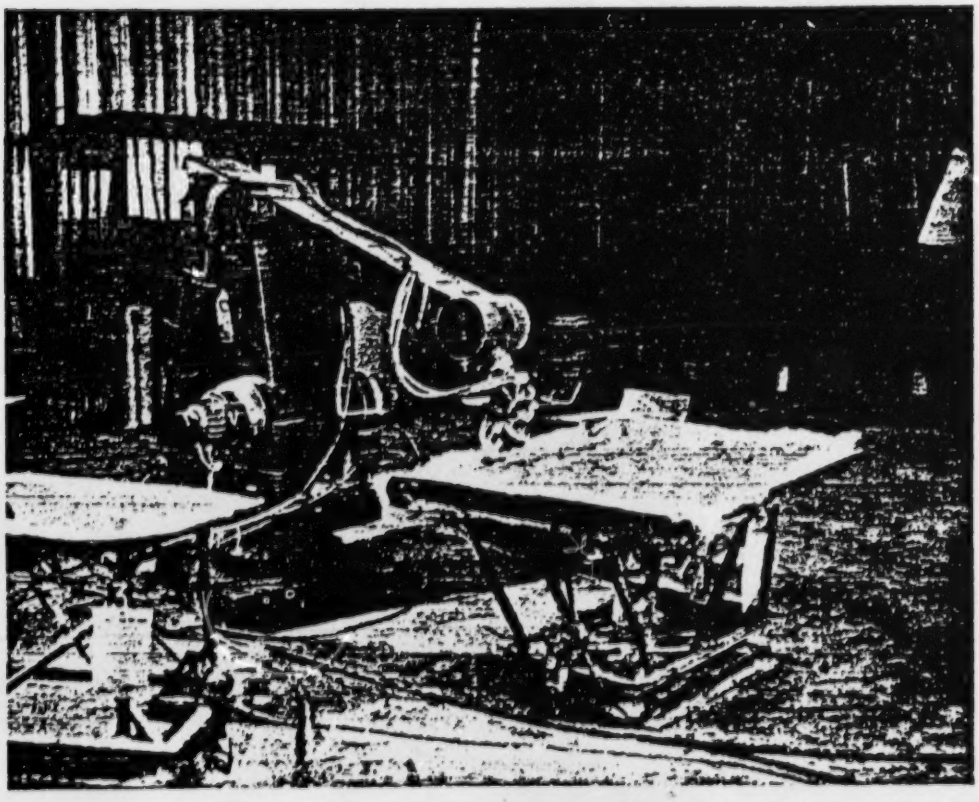
A DeVILBISS/TRALLFA ROBOT, EQUIPPED WITH AN ELECTROSTATIC SPRAY GUN , APPLIES A LIQUID COATING TO BICYCLE FRAMES (PHOTOGRAPH COURTESY OF THE DeVILBISS COMPANY)

EXAMPLE OF ROBOT WELDING APPLICATION



UNIMATE ROBOTS PERFORMING WELDING OPERATIONS ON AN AUTOMOBILE ASSEMBLY LINE. (PHOTOGRAPH COURTESY OF UNIMATION, INC.)

EXAMPLE OF ROBOT MACHINING APPLICATION



AN ASEA IRb-60 ROBOT ROUTS FIBERGLASS FOR AN AUTO BODY HOOD. (PHOTOGRAPH COURTESY OF ASEA, INC.)

ROBOT APPLICATIONS IN COMPANIES THAT USE ROBOTS

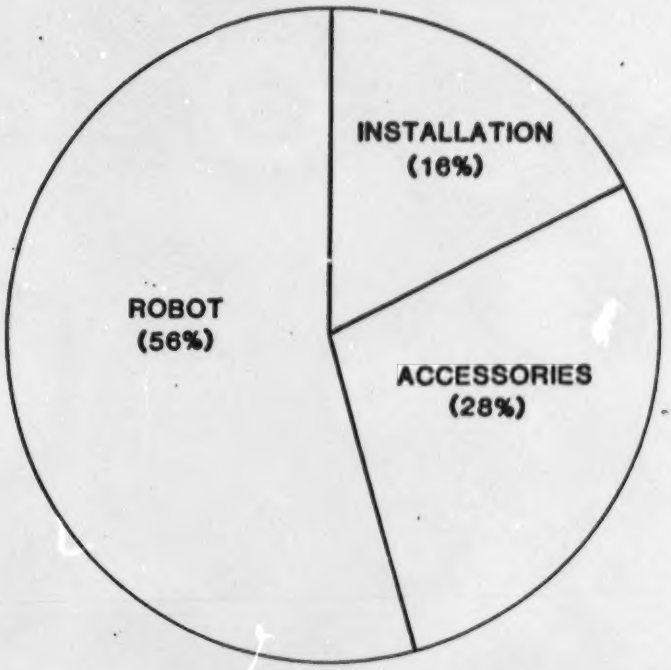
(300–400 MANUFACTURING PLANTS)

APPLICATION	% OF ROBOTS USED IN APPLICATION	% OF EACH APPLICATION PERFORMED BY ROBOTS
WELDING	40%	8%
MATERIAL HANDLING	25	2
MACHINE LOADING	20	3
SPRAY PAINTING	5	9
ASSEMBLY	3	2
MACHINING	2	1
OTHER	5	<1
	100%	2%

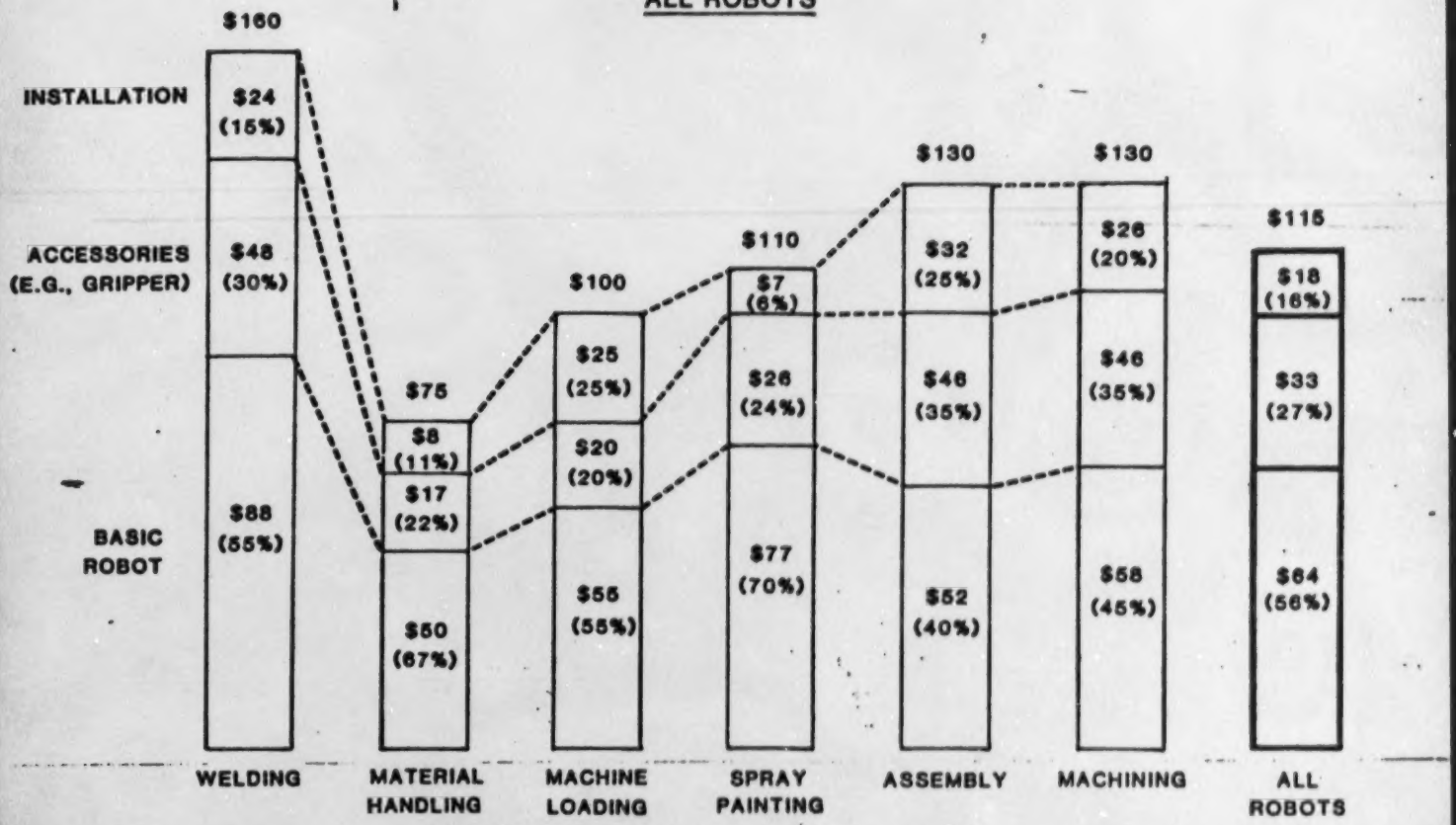
EXAMPLES OF CURRENT ROBOT APPLICATIONS

MANUFACTURING OPERATION	SAMPLE ROBOT APPLICATIONS
MATERIAL HANDLING	• Moving parts from warehouse to machines • Depalletizing wheel spindles into conveyors • Transporting explosive devices • Packaging toaster ovens • Stacking engine parts • Transfer of auto parts from machine to overhead conveyor • Transfer of turbine parts from one conveyor to another • Loading transmission cases from roller conveyor to monorail • Transfer of finished auto engines from assembly to hot test • Processing of thermometers • Bottle loading • Transfer of glass from rack to cutting line • Core handling • Shell making
MACHINE LOADING/UNLOADING	• Loading auto parts for grinding • Loading auto components into test machines • Loading gears onto CNC lathes • Orienting/loading transmission parts onto transfer machines • Loading hot form presses • Loading transmission ring gears onto vertical lathes • Loading of electron beam welder • Loading cylinder heads onto transfer machines • Loading a punch press • Loading die cast machine
SPRAY PAINTING	• Painting of aircraft parts on automated line • Painting of truck bed • Painting of underside of agricultural equipment • Application of prime coat to truck cabs • Application of thermal material to rockets • Painting of appliance components
WELDING	• Spot welding of auto bodies • Welding front end loader buckets • Arc welding hinge assemblies on agricultural equipment • Braze alloying of aircraft seams • Arc welding of tractor front weight supports • Arc welding of auto axles
MACHINING	• Drilling aluminum panels on aircraft • Metal flash removal from castings • Sanding missile wings
ASSEMBLY	• Assembly of aircraft parts (used with auto-rivet equipment) • Riveting small assemblies • Drilling and fastening metal panels • Assembling appliance switches • Inserting and fastening screws
OTHER	• Application of two-part urethane gasket to auto part • Application of adhesive • Induction hardening • Inspecting dimensions on parts • Inspection of hole diameter and wall thickness

TYPICAL ROBOT SYSTEM COST BREAKDOWN



ALL ROBOTS



BY APPLICATION ($000)

ROBOT APPLICATION CHECKLIST

	WEIGHT	APPLICATION CANDIDATES					
		1.		2.		3.	
BASIC REQUIREMENTS		YES	NO	YES	NO	YES	NO
ORDERLY ENVIRONMENT							
REPETITIVE OPERATION							
CYCLE TIME OVER 3 SECONDS							
NO JUDGEMENT REQUIRED							
UNIFORM PARTS							
MEETS INVESTMENT CRITERIA							
DESIRED CHARACTERISTICS							
HAZARDOUS ENVIRONMENT	10						
MONOTONOUS OPERATION	9						
DIFFICULT HANDLING	8						
MULTI-SHIFT OPERATION	7						
MEDIUM PRODUCTION VOLUME	7						
MEDIUM COMPLEXITY OPERATION	6						
MANAGEMENT SUPPORT	4						
WORKER/UNION SUPPORT	4						
IMPROVED PRODUCTIVITY	4						
IMPROVED PRODUCT QUALITY	3						
POTENTIAL FOR SEVERAL ROBOTS	3						
FEW INSTALLATION PROBLEMS	2						

Whither Technology:

At the present time, robots have only limited decision making capabilities of a simple binary type and absolutely no judgement. Using yes-no sensors, such as photo-cells and limit switches, they can determine:

* Is the part present so it can be picked up?
* Is the press or die cast machine open?
* Is the car to be welded a two-door or four-door?

More elaborate and useful sensing systems are now readily available. Included are:

* Vision systems which can tell a robot the exact loaction and orientation of parts to be manipulated.
* Vision systems which can help a robot guide an arc-welding torch along a seam to be welded.
* Force sensing for a robot wrist which can detect obstructions or the jamming of partial assemblies.

In addition, the affordable cost of more complex controls containing large scale integrated memories and microprocessors is enhancing the robots capability to deal with more and more complex tasks. In performing an assembly, when a force sensor indicates difficulty in mating parts, the robot can wiggle the parts to get them to go together, and if that fails, discard the first part and try again with another. The evolution of robotic programming languages (such as Unimation, Inc's VAL) allow the user to instruct the robot, through a keyboard terminal, in simple terms to do complex tasks such as stacking parcels on a pallet, interweaving the successive layers so that the pallet load remains intact during transport.

Robots can now be combined into manufacturing groups under the direction of a mini-or micro computer in which each robot can report on the present status, the number of operations performed, conformance with an allotted time constraint, and even the occurrence and nature of a breakdown.

One final observation regarding overall manufacturing technology. Putting robots into the scene on the factory or foundry floor has proven to be synergistic. As a tool for the industrial or manufacturing engineer, the orderliness and regularity of robotic operations has allowed him first of all, to do orderly, precise studies of the process, thus increasing the engineering data base, and secondly, allows him a degree of control and prediction which enhances the use of a well-structured management information system.

EXAMPLES OF CURRENT RESEARCH EFFORTS

ROBOT CAPABILITY	RESEARCH PROGRAMS
SENSING	• COMPUTER ANALYSIS OF IMAGES • 3D, STEREO EDGE, TEXTILE VISION • TACTILE SENSING • FORCE SENSING • CAMERA SYSTEMS • PATTERN RECOGNITION • INTERFACE DEVELOPMENT • MULTIPLE LIGHT SOURCES AND MOTION TO ANALYZE SCENES • RADAR, SONAR, AND INFRARED SENSING • TV/DIGITAL INTERFACE • COLLISION AVOIDANCE
GRIPPER DESIGN	• MULTI-FINGERED FLEXIBLE GRIPPER • FORCE SENSING PARALLEL JAW GRIPPERS • 3-FINGERED FLEXIBLE GRIPPER • 2-FINGERED MULTIPLE GRIPPER WITH SENSING
ROBOT CONTROL	• ADAPTIVE, FLEXIBLE LINKAGES • CARTESIAN FORCE CONTROL TRACKING • COOPERATING MANIPULATORS • SELF LEARNING CONTROL • INTEGRATION WITH CNC • CONTROL SYSTEM FOR ROBOT SAFETY • INTEGRATIVE FEEDBACK LOW-LEVEL COMPUTER CONTROL • DYNAMICS, KINETICS, INERTIA
PROGRAMMING	• HIGHER LEVEL LANGUAGE DEVELOPMENT • GEOMETRIC MODELLING • REAL TIME INTERACTIONS BETWEEN SENSORS AND CONTROL SYSTEMS • OFF-LINE PROGRAMMING • PROGRAMMING LANGUAGES FOR NON-TECHNICAL INDIVIDUALS • SOFTWARE FOR VISION SYSTEM
ROBOT ARM DESIGN	• HIGH PERFORMANCE ARM • GEARING, STEPPER vs DC MOTOR • GREATER PRECISION
OTHER	• COMPLIANCE • ARTIFICIAL INTELLIGENCE (SPEECH, VISION) • ROBOT MOBILITY • IMPACT OF ROBOT INTRODUCTION ON EMPLOYEES • MAN-MACHINE INTERFACE

Training For Robotics:

Although robot capabilities have improved substantially in recent years, the level of understanding of how to apply them has not kept pace. This is particularly unfortunate when we consider the broad spectrum of those involved, ranging from the managers who make the economic decisions, through the manufacturing managers who must increase productivity and and quality, to the technically oriented who must oversee their use and maintenance.

Fortunately, the problem is not unrecognized. Some of the most important people who are the influential leaders in guiding us toward the future have taken positive steps in forming definitive goals and objectives leading toward seizing the benefits that are extended to us. At all levels awareness is apparent. In general, the problems being addressed are:

* Extending the technology in robotic application.
* Developing new techniques to enhance robot capabilities.
* Defining and quantizing the ways in which robotics changes our perception of manufacturing science.
* Codifying the manufacturing data base to utilize new perceptions in design, manufacture, metrology and control, to increase our ability to provide goods which are low in cost, durable, dependable and reliable.

What are we doing to extend the utility of robots? The number of secondary institutions which are inculating programs in the field of robotics has more than doubled between 1979 and 1982; this involves a financial commitment greater than robotic industrial expenditure for R&D in the same period.

What are we doing to extend the awareness of the productivity advances to be gained by means of robotics? There is a proliferation of media articles, instructive seminars, books, articles and workshops which not only encourage managers to learn but make it easy for them to obtain concise, definitive information in the most efficient way.

What are we doing to prepare the technical community? All over the country technical schools, community colleges and professional institutes are offering well founded programs which even include hands-on training with a variety of robot types.

How does the technical training institution prepare a curriculum in robot application and maintenance? The first source is the robot manufacturer. Every one of them is eager to share their experiences in providing assistance and assurance to prospective users. The second source is the professional societies who maintain and publish articles, papers, and reference bibliographies and who encourage active correspondence aimed towards furthering the awareness and knowledge of anyone with an interest. Finally, the experience of other institutions in establishing meaningful programs is readily available and generously offered. A bibliography suggesting sources of reference is appended.

Bibliography:

Publications:

Engelberger, J.F., "Robotics in Practice", Amacon Division of American Management Associations, 1980.

Sanderson, Campbell, and Meyer, "Industrial Robots: A Summary and Forecast for Manufacturing Managers" Tech-Tran Corporation, Napierville, Illinois. 1982.

Tanner, William R., "Industrial Robots, "Volumes I and II, Society of Manufacturing Engineers, Dearborn, MI., 1981.

"Proceedings .... Robotics III, IV, V & VI Conference," Society of Manufacturing Engineers, 1978 thru 1981.

Schrieber, Rita R., "Meeting the Demand for Robotics Technicians," Robotics Today, 1981.

Carrico, Lloyd R., "Robotics Training: A Comprehensive Plan," Robotics Today, 1982.

Malstrom, Eric M., "Developing a University Robotics Laboratory Under 1980's Fiscal Constraints," Education Report Series, Society of Manufacturing Engineers ER82-05

Malstrom, Eric M., "Ingegrating Robotics into Engineering Education," Engineering Research Institute, Iowa State University, 1982.

Periodicals:

Robotics Age
P. O. Box 725
La Canada, CA 91011

Robotics Today
One SME Drive
P. O. Box 930
Dearborn, MI 48128

Robotic Associations:

Robot Institute of America
One SME Drive
P. O. Box 930
Dearborn, MI 48128

Robotics International of SME
One SME Drive
P. O. Box 930
Dearborn, MI 48128

Academic Resources:

Macomb County Community College
Warren, Michigan

Education and Training Committee
Robotics International of SME
Dearborn, Michigan

National Center for Research in Vocational Education
Ohio State University
Columbus, Ohio

Predmont Technical College
Greenwood
South Carolina

Industrial Resources:

Unimation, Inc.
Shelter Rock Lane
Danbury, Conn. 06810
P.J. Rosato
Director of Training and Technical Publications

General Electric Co.
Manufacturing Engineering Consultation and Applications Center
Schenectedy, N.Y.
D.L. McMann
Manager, Training and Communications

Prab Robots, Inc.
Kalamazoo, MI.
R.R. Trouthead
Manager of Sales Administration

For a more comprehensive, yet authoritative, summary of the present situation in robotics, the author recommends:

Industrial Robots: A Summary and Forecast for Manufacturing Managers.
Published by:

Tech Tran Corporation
134 N. Washington Street
Napierville, IL 60540
(312/369-9232)

TRAINING FOR ROBOTICS

- EXTENDING THE TECHNOLOGY IN ROBOTIC APPLICATION.
- DEVELOPING NEW TECHNIQUES.
- EXTENDING OUR PERCEPTION OF MANUFACTURING.
- ENHANCING THE DATA BASE.
- UNIVERSITY PROGRAMS IN NEW DEVELOPMENT.
- TECHNICAL AND COMMUNITY COLLEGE REINFORCEMENT OF FUNDAMENTALS IN POWER, CONTROL, METROLOGY.
- SOURCES - MANUFACTURERS, PROFESSIONAL SOCIETIES, PIONEERS IN EDUCATION.

SAMPLE ROBOT ECONOMIC ANALYSIS FORM

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
EXPENDITURES										
1. ROBOT	$66,000									
2. ACCESSORIES	30,000									
3. INSTALLATION	18,000									
4. SPECIAL TOOLING	6,000									
5. OTHER (10% TAX CREDIT)	(12,000)									
6. TOTAL	$108,000	0	0	0	0	0	0	0	0	0
OPERATING SAVINGS (COSTS)										
7. DIRECT LABOR	$70,000									
8. INDIRECT LABOR	(1,500)									
9. MAINTENANCE/REPAIR	(3,000)									
10. OPERATING SUPPLIES	(1,000)									
11. (DEPRECIATION)	(12,000)									
12. OTHER SAVINGS (COSTS)										
13. TOTAL	$52,500									
ANALYSIS										
14. TOTAL EXPENDITURES	$(108,000)	0								
15. TOTAL SAVINGS	52,500	52,500								
16. NET BEFORE TAX (15-14)	(55,500)	52,500								
17. NET AFTER TAX (16 x .52)	(28,860)	27,300								
18. NET CASH FLOW (17-11)	(16,860)	39,300								
19. DISCOUNT FACTOR (20%)	.833	.694	.578	.482	.402	.335	.279	.233	.194	.162
20. DISCOUNTED CASH FLOW (18 x 19)	(14,050)	27,274	22,715	18,943	15,799	13,165	10,965	9,157	7,624	6,367
21. CUMULATIVE CASH FLOW	(14,050)	13,224	35,939	54,882	70,681	83,846	94,811	103,368	111,592	117,959

NET PRESENT VALUE = $118,000

PAYBACK = 1.5 YEARS

CURRENT ROBOT PROBLEM AREAS OR NEEDED IMPROVEMENTS, AS VIEWED BY ROBOT MANUFACTURERS, RESEARCHERS, AND USERS

KEY: ● = MAJOR PROBLEM/NEED
◑ = MODERATE PROBLEM/NEED
○ = MINOR/NO PROBLEM

	PROBLEM AREA/ IMPROVEMENT NEEDED	ROBOT MANUFACTURERS	ROBOT RESEARCHERS	COMPANIES PLANNING TO USE ROBOTS	COMPANIES THAT USE ROBOTS
ROBOT CAPABILITIES	1. LOW COST, EFFECTIVE VISION SENSING	●	●	●	●
	2. EASIER, STANDARDIZED PROGRAMMING	●	●	◑	●
	3. IMPROVED GRIPPER DEXTERITY	●	○	◑	◑
	4. GREATER FLEXIBILITY–NUMBER OF APPLICATIONS	○	◑	◑	◑
	5. LOW COST, EFFECTIVE FORCE SENSING	○	◑	◑	○
	6. LIGHTER, SMALLER ROBOTS	◑	○	○	○
	7. IMPROVED CONTROL SYSTEMS	○	◑	○	○
ROBOT PERFORMANCE	1. GREATER SPEED	◑	○	○	◑
	2. IMPROVED POSITIONING ACCURACY (WITHIN±.005")	◑	◑	○	◑
	3. IMPROVED REPEATABILITY	◑	◑	○	◑
	4. IMPROVED RELIABILITY	○	○	○	◑
OTHER NEEDS	1. REDUCED ROBOT COST	●	◑	●	●
	2. IMPROVED ABILITY TO INTERFACE WITH EXISTING EQUIPMENT	◑	○	○	◑
	3. IMPROVED SAFETY	○	◑	○	○
	4. TURNKEY SYSTEMS	◑	○	◑	○